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Procedia Technology 17 (2014) 557 – 565

Procedia Technology

Conference on Electronics, Telecommunications and Computers – CETC 2013

AND, OR, NOT logical functions in a SiC tandem device

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Abstract

In this paper we demonstrate the basic AND, OR and NOT logical functions based on SiC technology. The device consists of a p-i'(a-SiC:H)-n/p-i(a-Si:H)-n heterostructure with low conductivity doped layers. Experimental optoelectronic characterization of the fabricated device is presented and shows the feasibility of tailoring channel bandwidth and wavelength by optical bias through illumination in the back and front sides. Results show that, front background enhances the light-to-dark sensitivity of the long and medium wavelength range and strongly quenches the others. Back violet background has the opposite behavior; it enhances the magnitude in short wavelength range and reduces it in the long ones. This nonlinearity provides the possibility for selective removal or addition of wavelengths. Each digital signal is composed by two wavelengths, one from the long and the other from the short range. One digital signal is the Red-Blue pair and the other the Green-Violet pair. Two digital light signals Manchester coded at 6000 Baud are applied do the front side of the device while violet light steadily shines either on the back or front side. Each signal pair will be presented first, independently, allowing the NOT logical function to be identified. The violet background biasing either in front or at the back of the device will allow for a non inverted or inverted signal. The interaction of two digital signals, (Red-Blue and Green-Violet pairs) will consequently be shown and the logical AND, OR operations identified by selecting the violet biasing illumination at either the back or front side of the device. The XOR logical function can also be identified along with the other logical functions. Experimental results are shown and explained with the two digital signal pairs.

Peer-review under responsibility of ISEL – Instituto Superior de Engenharia de Lisboa, Lisbon, PORTUGAL.

Optoelectronics, Digital light signal, Logical functions, SiC Technology

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Peer-review under responsibility of ISEL – Instituto Superior de Engenharia de Lisboa, Lisbon, PORTUGAL.
doi:10.1016/j.protcy.2014.10.262

1. Introduction

Present computing systems rely in hardware that is based in digital logical functions of Boolean algebra[1]. Any other platform that offers these logical functions may also provide computing systems. Many efforts are being done worldwide for smaller, faster and different approaches for logical calculus. Quantum-dot cellular automata (QCA) is one of the promising new technologies for future generation ICs that overcome the scaling limitation of CMOS[2]. The fundamental unit of QCA-based design is the majority gate; hence, efficient construction of QCA circuits using majority gates has attracted a lot of attention. Since every QCA circuit can be implemented by using only majority and inverter gates, the inverter becomes another important component in constructing QCA circuits. Majority logic[2] is another way of implementing digital operations in a manner different from that of Boolean logic. The logic process of majority logic is more sophisticated than that of Boolean logic, and consequently more powerful for implementing a given digital function with a smaller number of logic gates. One of the most important component in any arithmetic and digital circuits in QCA and VLSI (Very Large Scale Integration) is the full adder [3], [4].

2. Sensor operation and characterization

The sensor is a two stacked p-i-n structures (p(a-SiC:H)-i'(a-SiC:H)-n(a-SiC:H)-p(a-SiC:H)-i(aSi:H)-n(a-Si:H)) between two transparent contacts one at each end. The thicknesses and optical gap of the i'- (200nm; 2.1 eV) and i- (1000nm; 1.8eV) layers are optimized for light absorption in the blue and red ranges[5]. Based in silicon carbon technology[6] this structure can be seen in Fig 1 where the wavelength arrows indicate the absorption depths during operation and λ_V, λ_B, λ_G, λ_R the digital light signals within the visible spectrum.

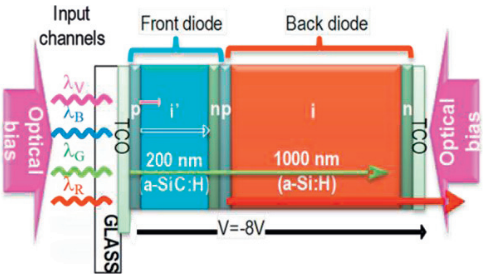


Fig 1- Sensor structure and operation

Light sources are the output of general purposes LEDs. These light sources are for low intensity input digital signals and for optical bias by strong intensity of either back or front background illumination at each side of the device. Different wavelength signal sources are used: violet (400nm), blue (470nm), green (524nm) and red (626 nm). For background lighting the same violet wavelength is applied in a continuous and steady flux.

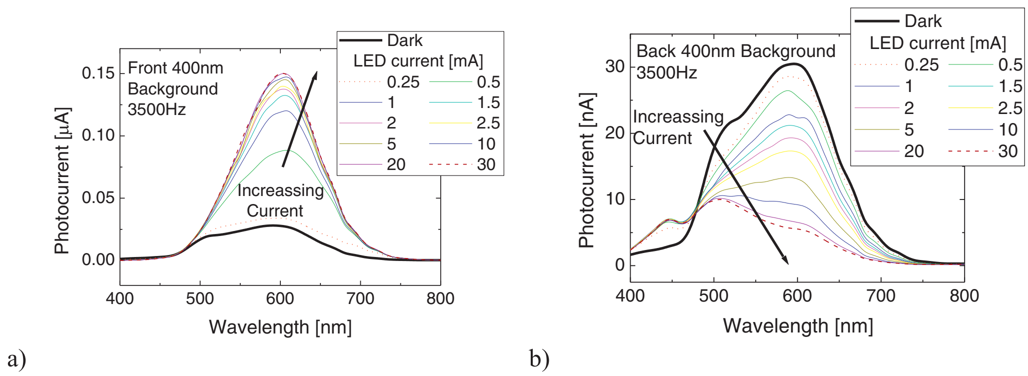
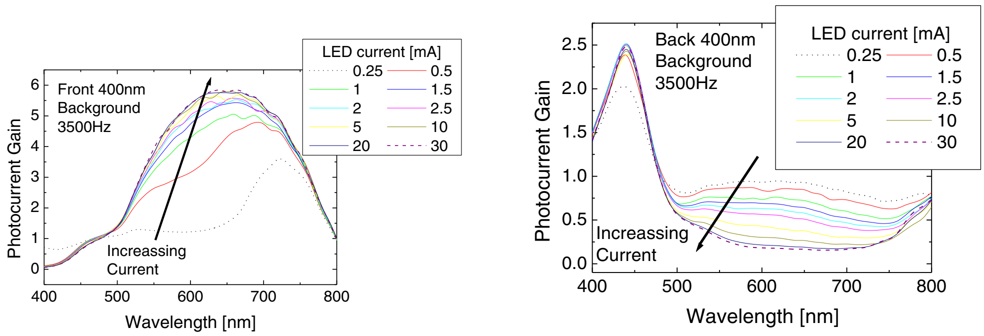


Fig 2 – Photocurrent with a) front and b) back lighting of the background.

The sensor is electrically biased with -8V. Photocurrent readings were accomplished with a monochromator in 10nm steps from 400 to 800nm and presented in Fig 2.

Experimental results of Fig 2a) show the photocurrent's increase in the 470-700nm bandwidth.

The presence of a low intensity violet light at the front background significantly increases the photocurrent. The LEDs current increase from 0 to 0.5mA generates an increase in photocurrent which is outstanding when compared to the increase of the LED current from 0.5 to 30mA. In Fig 2b the thick black curve is the same of the previous figure and represents the dark level. With increasing LED current the photocurrent in the 470-700nm bandwidth gradually decreases and there is an almost fixed increase of the photocurrent in the 400-470nm bandwidth. The photocurrent gain is the ratio between the photocurrent output and the value of the dark curve when there is no background lighting. This gain is shown in Fig 3.



a) b)

Fig 3 – Photocurrent gain when background light is at the a) front and b) back side of the device.

The spectral gain, shown in Fig 3a) with front background, reduces the short wavelengths (<470nm) and increases the long (>470nm) wavelengths. This behavior is that of a selective filter centered in 650nm. The opposite happens when the background lighting is set at the back of the sensor, Fig 3b), the short wavelengths increase while the long wavelengths decrease. This is also a selective filter but centered in 440nm. Thus the sensor can act as a selective filter, where the gain of the short and long pass wavelengths is controlled by optical bias at either one of the sides. The gains of both filters suffer almost no changes with LED currents above 10mA.

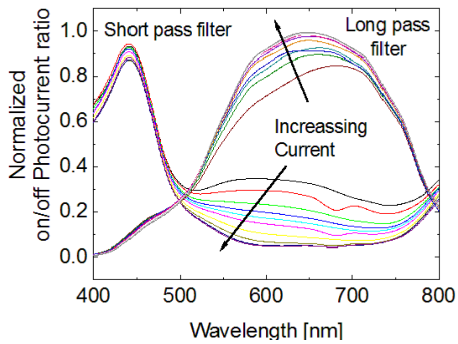


Fig 4 – Short and long pass filters.

Normalizing the photocurrent gains shown in Fig 3 and plotting them in the same graph, Fig 4, enables a view of the two filters. The eye figure assures the effectiveness of the filtering capabilities of the sensor. The input digital light intensity 50µW/cm^2 is very low compared to the background lighting 2800µW/cm^2.

3. Logical functions

Logical functions are commonly used in hardware as logic gates [7] and by combining them, other logical functions are created, and some, due to their special function, are named. One of them is the multiplexer which is a combinational function. Due to its behaviour the multiplexer can also be used as a basic circuit which in turn can produce results as simple as the basic logic gates. This functionality is presented in Fig 5.

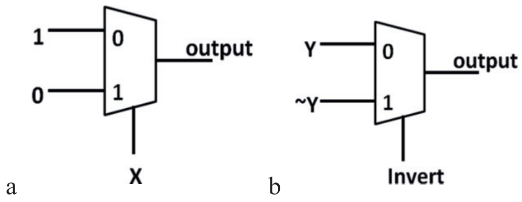


Fig 5 – A multiplexer used as an invert function.

The 2x1 multiplexer shown in Fig 5a) is composed by a selector input, X, which chooses one of the input signals to be set as the output. When X hold the 0 value, the 0 input is set at the output, in this case the output presents the value 1. Accordingly, when X is 1 the output is 0. This means that the output is the inverse of X.
In Fig 5b the Invert signal is the selector that chooses between inputs Y and ~Y (NOT Y). The output follows the Y signal when the Invert selector is 0 and follows the ~Y signal when Invert is 1. By this setup, the Invert selector can choose between a Y signal or its inverse. This is the basis of the following work using the sensor's capability of being a multiplexer [8]to act as an inverter.

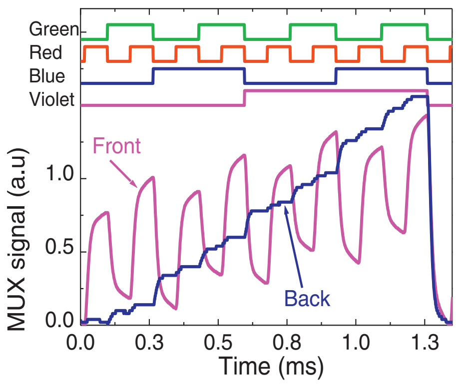


Fig 6 – The multiplex function.

Presented in Fig 6 is the multiplex/demultiplex function of the SiC sensor. By choosing the front background the output signal follows the influence of the red and green digital light signals, and the back side lighting allows the output to follow the blue and violet signals. The patterns in the top of the figure are displayed to guide the eyes into the output signal. According to Fig 4 the red and green wavelengths belong to the long wavelengths whereas the blue and violet wavelengths belong to the short wavelengths. Having in mind that choosing the background side chooses the wavelengths that are present at the output, and the behaviour of the multiplexer in Fig 5b) it is possible to have a Y signal that belongs to the long wavelengths and a ~Y signal that belongs to the short wavelengths. This is presented in Fig 7.

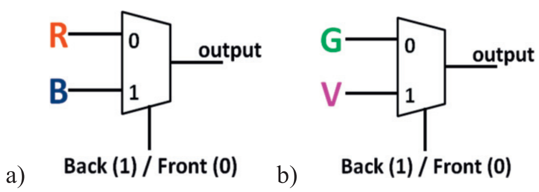


Fig 7 – Digital light multiplexer.

The digital light multiplexer presented in Fig 7 works in the following way: the selector illuminates the background either at the front (0) or at the back (1), thus choosing a long wavelength (R or G) to be presented as output or the short wavelength (B or V). According to Fig 5b), the R signal must have its inverse equal to ~B, and the G signal its inverse equal to ~V. The long, short wavelength pair forms a digital light signal and is represented by *Signal[Long, Short]*. In the experimental results that follow two different digital light signals will be used, signal D [Red, Blue] and signal P [Green, Violet].

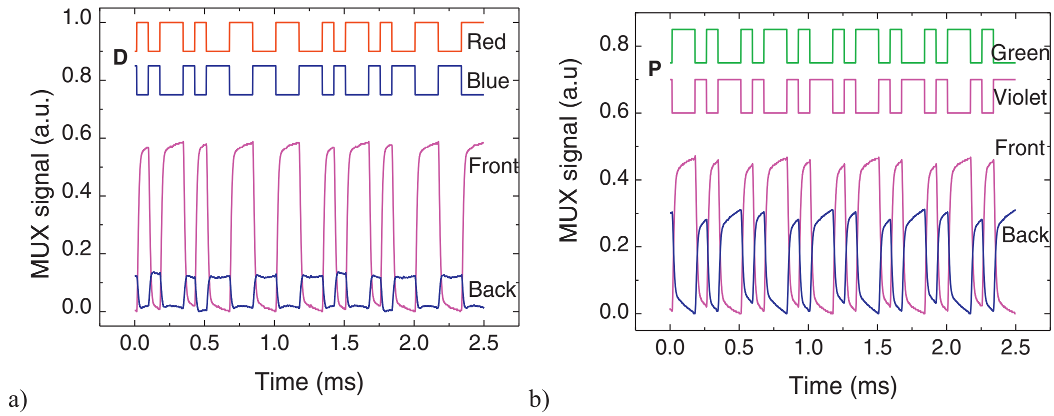


Fig 8 – Two digital light signals a) D[R, B] and b) P[G, V].

Plotted in Fig 8a) is the resultant output signal under front and back illumination for the same input digital light signal D[R, B]. The waveforms at the top of the figure represent the on/off input sequence. The front output follows the Red component of the digital signal and the Back follows the Blue component. Fig 8b) is identical in its behavior, were the output signal with back lighting follows the Green component and the back waveform follows the Violet component. This shows the inverse function with two different examples.

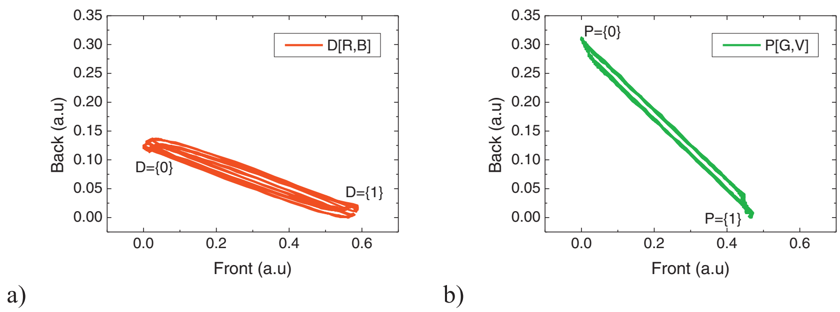


Fig 9 – Independent digital light signals a) D [R,B] , b) P[G,V]

Digital light signals D[R,B] and P[G,V] presented in Fig 8 were independently impinged on the sensor yielding two time dependent waveforms front and back that were recorded at different instances in time but synchronized with the input digital light signal, thus with the same phase. The backs vs. front signals were plotted for each individual input signal and these are plotted in Fig 9.

Regarding Fig 9a) and in relation to Fig 8a), the D[R,B] digital signal is 1 when the front signal has its highest value and the back signal its lowest, and on the other hand D signal is 0 when the front has its lowest value and the back it highest. The same confrontation can be made with Fig 8b) and the P[G,V] line plotted in Fig 9b).

When both signals are impinged simultaneously on the sensor, their interaction is plotted in Fig 10.

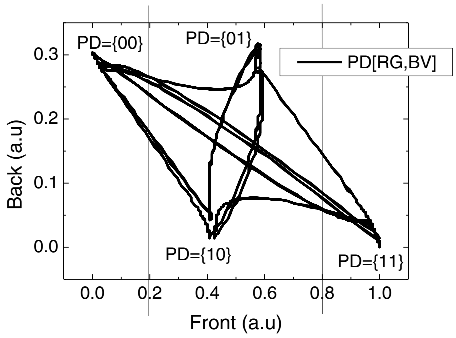


Fig 10 – Interaction of digital light signals D[R,B] , P[G,V]

In Fig 10 the vertexes of the plotted figure represent the four possible combinations of the two digital light signals D[R,B] and P[G,V]. To clearly identify the resultant interaction of digital light signals D and P two threshold lines can be set at 0.2 and 0.8 (a.u). These two threshold line are the same ones set in Fig 11a) through Fig 13. In the presence of signal noise including jitter, the vertexes will be represented by a probability area and this will bring up the necessity of setting threshold lines in the back signal axes (not shown).

The interaction in time line of the digital signals D and P signals is shown in Fig 11. To simplify the figure, only the long components of digital light signal D (Red) and P (Green) are shown.

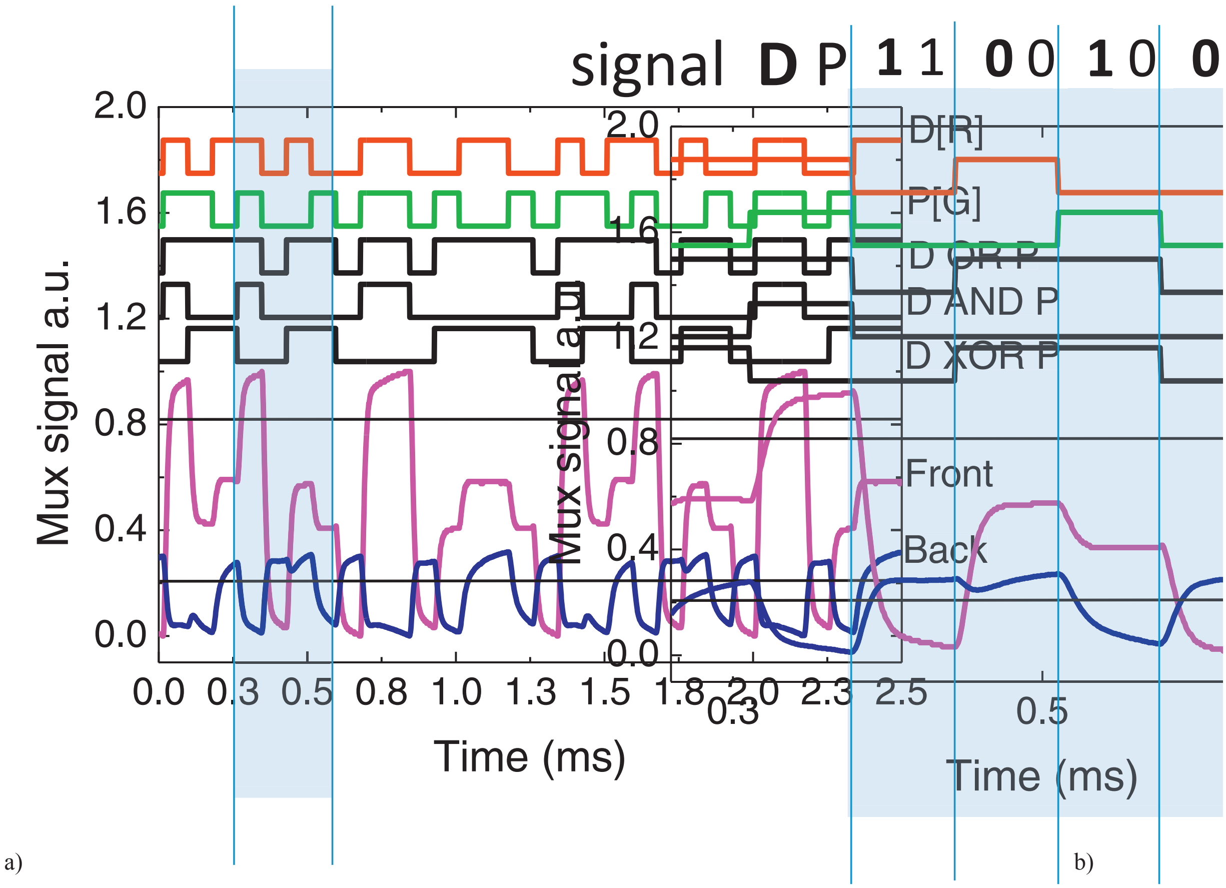


Fig 11 – Interaction of light signals a) D[R, B] and P[G, V] , b) shaded detail of a)

The two digital signals D and P applied simultaneously to the sensor are depicted in Fig 11a). There are four different combinations. The shaded part in the figure holds these combinations and that detail is shown in Fig 11b). The same detail for each of the logical functions is shown in figures Fig 12 and Fig 13. Sampling is made in the middle part of each bit.

The waveforms at the top of Fig 12a) show the four different combinations of the two digital light signals D and P. The output signal under front illumination is also depicted. By setting a threshold value above the minimum value of the output signal and assuming that values above the threshold have a logic value of 1 and the values below the line the logic value 0, the result is equal to the expected OR waveform. The sensor is thus capable of the OR logical function (disjunction).

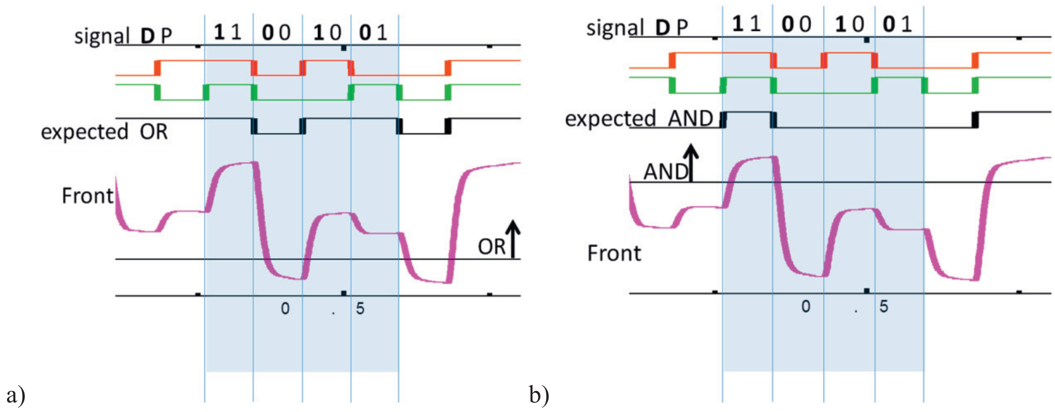


Fig 12 – a) The OR function b) The AND function.

Depicted in Fig 12b) is the same figure of Fig 12a) but with a different threshold line. The threshold line is slightly below the maximum value of the output signal under front background lighting. Values above the threshold line are considered as a logic value of 1, and those below the threshold line have logical value 0. Comparing this result with the expected AND waveform both coincide showing that the sensor is also capable of the AND logical function (conjunction).

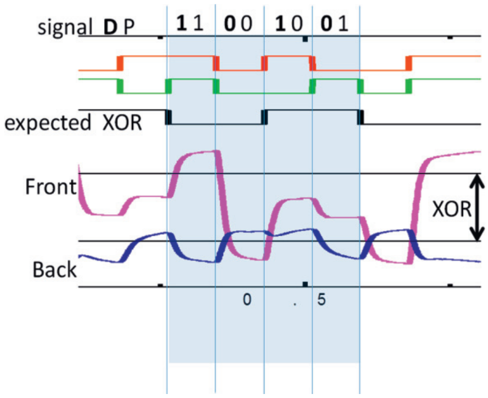


Fig 13 – The XOR function

The same description of Fig 12a) is applied to Fig 13 which is completed with both threshold lines and the output under back illumination of the background seen in the detailed part of Fig 11a). Using both threshold lines and setting the logic value 1 whenever the output signal under front illumination is in between the threshold lines, and setting the logic value 0 otherwise, results in the equivalent values of the expected XOR waveform. The XOR function can also be identified by the following observation: comparing the output under front illumination with the output under back illumination, the expected XOR waveform has value 1 whenever front and back signal lines are both at a local maximum or local minimum and a logical value of 0 when one is at a local maximum and the other at a local minimum. This also equals the expected XOR wavelength showing that the sensor is also capable of the XOR logical function (exclusive disjunction).

4. Conclusions

The study of the SiC:H sensor as a multiplexor/demultiplexor device experimentally shows the possibility of determining the full 16 combinations of four digital inputs. The SiC:H sensor has the characteristic of a tunable filter in two distinct bandwidths, the long and short wavelengths. Defining a digital light signal as the combination of two wavelengths, one from the long and other from the short bandwidth it is possible to identify the inverse function using the tunable filter characteristic. The interaction of two digital light signals allow for the identification of other basic logical functions: AND, OR. A more complex digital function, like the XOR is also a possible outcome of the sensor. The work that is under development aims for the identification of other complex logical and arithmetic functions as the majority and the adder.

Acknowledgements

This work was supported by FCT (CTS multi annual funding) through the PIDDAC Program funds and PTDC/EEA-ELC/111854/2009 and PTDC/EEA-ELC/120539/2010.

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